IV. "Effects of prolonged Heating on the Magnetic Properties of Iron." By S. R. Roget. Communicated by Professor Ewing, F.R.S.

V. "On the Connection of Algebraic Functions with Automorphic Functions." By E. T. Whittaker. Communicated by Professor Forsyth, F.R.S.

The Society adjourned over Ascension Day to Thursday, May 26.

"A Calorimeter for the Human Body." By William Marcet, M.D., F.R.S. Received March 10,—Read April 28, 1898.

(From the Physiological Laboratory, University College, London.)

At the meeting of the Physiological Society held at University College in March, 1897, I exhibited and described a calorimeter constructed for the purpose of determining the heat given out by man. Several members of the Society, in succession, allowed themselves to be shut up in the chamber where they experienced no discomfort whatever. The instrument was also described the same year to the Société de Physique et d'Histoire Naturelle of Geneva, but no full account of it has been published so far.

The first calorimeter for the investigation of animal heat was made by Lavoisier and Laplace,* who enclosed an animal in a chamber surrounded with ice and determined the heat evolved by measuring the amount of ice melted. Crawford, in 1788, placed the air chamber inside a water-jacket, and determined the heat emitted by means of the increased temperature of the water. An objection to this type of calorimeter is the very small rise in the water temperature, and the difficulty of obtaining an uniform temperature in such a large volume of water. J. Rosenthal,† in 1878, introduced a calorimeter in which the heat given out from a small animal was absorbed by a fluid with a low boiling point, such as ordinary ether, the amount of heat was calculated from the volume of the fluid evaporated and its known latent heat of vaporization.

Rosenthal,‡ at a later date, constructed a calorimeter, which consisted of three concentric chambers of sheet copper, and was made in duplicate; the two instruments were connected by means of a U-shaped manometer. The heat given out by an animal, such as a dog, enclosed in the innermost chamber of one of the instruments,

* 'Mémoires de l'Acad. des Sciences,' 1780.

† 'Archiv f. Anat. u. Physiol.' (Physiol. Abthg.), 1878, p. 349.

‡ C. Rosenthal, 'Arch. f. Anat. u. Physiol.' (Physiol. Abthg.), 1888. p. 1; J. Rosenthal, *ibid.*, 1889, pp. 1, 23, 39.

was communicated to the middle chamber, and from the position of the meniscus in the manometer, the initial temperature of the experiment and the barometric pressure, the heat emitted in a given time was indirectly calculated.

Experiments were made on man with a modified form of this instrument by enclosing an arm in one of the two inner chambers. Hirn* investigated the heat emitted by man by making use of a wooden chamber in which he had previously ascertained the rate of loss of heat through its walls. This was done by burning a known volume of hydrogen gas within the chamber until the temperature became constant, and then determining the heat lost per unit of time, from the known volume of gas burnt. This method at first sight commended itself by its simplicity, but was open to two objections—the first that it was an indirect method of inquiry, the second that the person under experiment was unavoidably subjected to a high temperature.

In 1889 Richet† published an elaborate investigation on animal heat, in which he made use of a calorimeter constructed in such a way that the heat emitted by an animal in a closed vessel displaced by pressure a volume of water equal to the expansion of the air in the calorimeter.

An ingenious animal-calorimeter was constructed lately by Messrs. J. S. Haldane, W. Hale White, and J. W. Washbourne.‡ These gentlemen determined the heat given out from an animal, by comparing the pressure resulting from the expansion of the air in a closed jacketed space surrounding the chamber containing the animal, with the corresponding expansion produced by the burning of a known volume of hydrogen gas in another similar vessel. The amount of gas burnt is regulated with a stopcock, so that its heat should correspond exactly with that produced in the other chamber as indicated by a differential manometer. The heat emitted is equal to that of the combustion of the gas burnt.

Messrs. W. O. Atwater and E. B. Rosa, of Connecticut, U.S.,§ have quite recently measured the heat emitted from a person by placing him in a large calorimeter, where he lived for periods of from one to twelve days. The walls of the chamber were double, and made of sheet copper and sheet zinc, while the heat generated was

* "La Thermodynamique et l'étude du travail chez les êtres vivants," 'Revue Scientifique,' 1897. 'Recherches sur l'Équivalent mécanique de la Chaleur.' Colmar, 1858, pp. 51, 95. 'Exposition analytique et expérimentale de la Théorie mécanique de la Chaleur.' Paris, 1875, p. 35.

† "La Chaleur animale," par Ch. Richet, 'Bibl. Sc. Internat.,' 1889.

‡ 'The Journal of Physiology,' 1894, p. 123.

§ "An Apparatus for verifying the Law of Conservation of Energy in the Human Body," Brit. Assoc., 1897, Toronto, Trans. of Sec. A (General Physics).

carried away by a stream of water; according to the authors, tests showed this calorimeter to be very accurate.

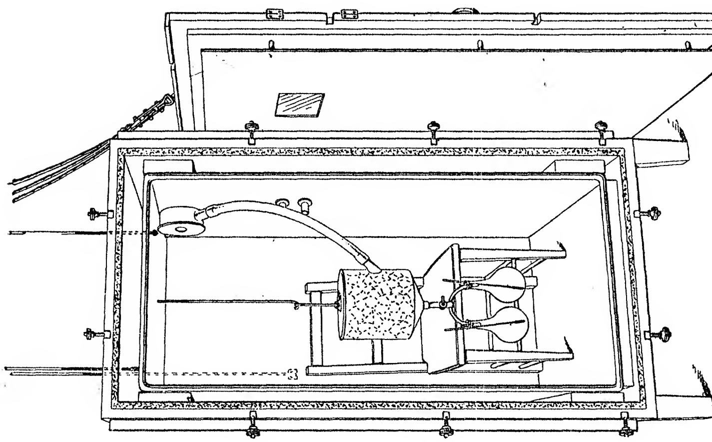
The construction of the present instrument was suggested from Berthelot's calorimeter, for the determination of specific heat by mixtures, in which the heat given out is reflected by bright surfaces of silvered copper surrounding at a short distance the vessel containing the mixture. It was found, however, in experimenting with the new calorimeter (which was not silvered inside), that all the heat was not reflected, a certain proportion being absorbed by the copper, which necessitated an arrangement for determining the temperature of the metal.

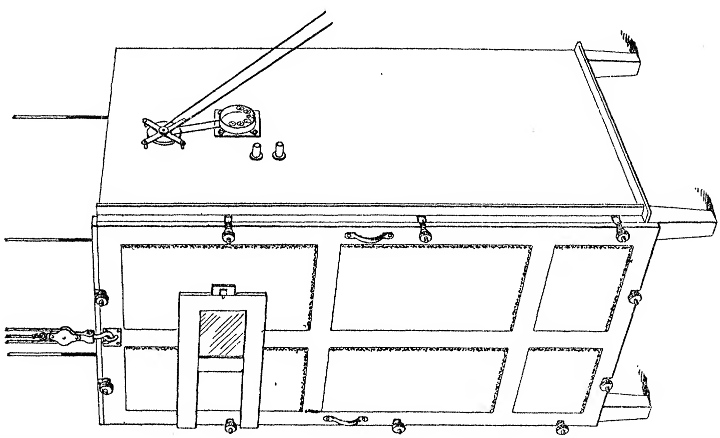
The instrument (see figure) consists of a wooden chamber lined internally with a thick padding of cotton wool, and externally with several thicknesses of felt. Inside this chamber there is another made entirely of sheet copper, the inner surface of which is maintained carefully polished; its height is 145 cm., and its breadth is 69 cm. The two chambers have between them an annular space from 4 to 5 cm. in breadth. The capacity of the copper chamber, empty, is 810·4 litres, and its weight 62·370 kilograms, therefore an alteration of 1° C. in the temperature of that mass of copper would be equal to 5832 (small) calories, or would raise 5832 grams of water 1° C.

The copper chamber is closed by means of a movable panel also constructed of copper, which is fixed to a wooden backing; the edge of the copper panel is made to press tightly against an india-rubber cushion carried round the rim of the opening in the copper chamber, while the edge of the wooden backing is applied against the rim of the wooden chamber, and the panel is kept in its place firmly with brass screws. This movable door is too heavy to be handled easily by one man, and on that account is fixed to a tackle fastened to a beam in the roof of the laboratory, by which means no difficulty is experienced in opening or closing the chamber.

There is a small window 21×15 cm., made of two superposed panes of very thick glass, and opening into the two chambers; when closed, the rim of the inner pane presses against a cushion around the corresponding opening in the copper chamber; it shuts by a spring bolt, and should the person under experiment feel uncomfortable, or wish to communicate with the outside, he can push open this window at any time.

Inside the copper chamber there are two ventilators, or perhaps more correctly "agitators," in the form of revolving fans, the object of which is to thoroughly mix the air inside the chamber. One of these agitators is fixed high up in the chamber, the other low down on the opposite side. The upper agitator was found experimentally to produce a blast of 190 litres per minute—say about 380 litres per





minute for the two; nearly the whole of the air in the chamber would be carried through the two agitators every two minutes.* The number of revolutions of the fans recorded by counters amounts together to two or three hundred thousand per hour.

The motor power for working the fans is obtained from the wires used for the electric light of the laboratory, and exerted through two small dynamos—one for each agitator, while the action of either one or the other can be regulated by a carbon-resistance.

* The resistance caused by the ice, and a rose jet on the track from the lower agitator, would probably reduce the draught to some little extent; no doubt, however, that the air is very thoroughly mixed inside the chamber.

The upper agitator is disposed in such a way as to drive the air of the chamber through a mass of ice roughly broken up, and held in a cylindrical tin vessel open at the top, suspended from the roof of the chamber. The cold air having from its increased density a tendency to fall, is taken up by the lower ventilator and driven upwards; by such means a circulation of the air in the chamber is maintained through the ice-holder. Should the temperature of the chamber rise during the experiment, by increasing the draught through the ice more ice is melted and the rise is checked; the reverse holds equally good.

The ice used for absorbing the heat emitted by the person under experiment delivers its water into a flask holding a thermometer divided into fiftieths of a degree centigrade; the flask and thermometer are both weighed. The flask hangs from a hook on the side of a tube projecting from the bottom of the ice-holder.

Besides the thermometer in the flask, there are three other thermometers all centigrade, also divided into fiftieths of a degree, connected with the calorimeter; the bulb of one of them projects into the copper chamber while its stem is carried outside above the wooden chamber; a second has its bulb fastened down to the side of the copper chamber by means of a strip of copper which covers it entirely, its stem also projecting outside; the third thermometer is passed through the wooden chamber into the annular space, whose temperature it shows during the experiment.

The successive stages of an experiment are as follows:—the heat emitted from the body is first rapidly distributed throughout the chamber, then it is absorbed by the mass of ice, reappearing in measurable form as water. Knowing that 79 calories are required for melting 1 gram of ice, the total calories corresponding to the ice melted are easy to calculate.

Some of the heat emitted falls upon the brightly polished surface of copper of the chamber, most of it is reflected into the chamber, but a certain proportion becomes absorbed in the metal, and is determined by the thermometer attached to the walls of the chamber. Perhaps a very small amount passes through the copper walls into the annular space, it might have been neglected, but has been taken into account in every experiment. A number of experiments showed that the copper was equally heated in every part, or very nearly so, while the test experiments made with hydrogen gas placed that question quite at rest.

The thermometers were generally read and the readings recorded every ten minutes, the temperature of the copper being used as a guide towards the maintenance of a constant temperature throughout the instrument.

It will be readily understood that a difference of as much as 1°

at the end of the experiment in the temperature of the air of the copper chamber was not of great moment from the low specific heat of air; indeed, such a difference would only yield 214 calories, which is but trifling on say, 90,000 calories given out in one hour. On the other hand, a slight difference in the temperature of the copper proved of importance on account of the mass of metal.

There was no difficulty, however, in maintaining the temperature of the copper within 0·3° or 0·4° of its original reading before the experiment. Should it accidentally run up beyond that figure, a very rare occurrence, this only lasted a minute or two, and by increasing the blast through the ice, the temperature of the copper was soon brought down to its initial reading. A similar remark applies to falling temperatures of the copper; by stopping the draught through the ice they soon rose to the initial reading. Of course, constant attention to the temperatures was required during the whole experiment, which, with but few exceptions, lasted one hour.

There remained, however, a serious difficulty to contend with, owing to the heat produced by the action of the ventilators or agitators.

At first the friction of the bearings on which the fans rotate was thought to be the main cause of this heat; and, in consequence, their position was altered so as to be placed entirely outside the wooden chamber. This, however, failed to mend matters, and it became evident that the friction of the revolving blades against the air was the source of the heat produced. The only method of overcoming the difficulty was to determine the heat produced exclusively by the agitators and subtract it from the total heat obtained in each experiment.

It was now found necessary to introduce counters registering the number of revolutions for each of the ventilators up to 1,000,000 turns. The inquiry necessitated by the ventilators (say agitators) took up a considerable portion of the winter 1896–97.

These experiments were carried out exactly in the same way as those made on the living body, with this difference, that while from 10 to 15 lbs. (4·5—6·8 kilograms) of ice were wanted when a human subject was under experiment, from 500 to 800 grams of ice only had to be used with the agitator experiments. The following is the result of one experiment taken at random amongst a great many others:—

	Chamber.	Annular space.	Copper.
Initial	15·59°	15·50°	15·35°
Final	15·55	15·52	15·50
	−0·04	+0·02	+0·15

Weight of ice melted........	97·46 grams.
T. water from ice	10·92°

Calories recovered.

From melted ice................	+7699
„ heat absorbed in water	+1064
„ „ of air in chamber	−9
„ „ air in annular space ..	+1
„ „ copper (of chamber) ..	+ 875
	9630
	(9 subtracted)

Number of revolutions of agitators...... 342,305

$342{,}305^2 = 11717....$

Unfortunately the heat produced by the revolving fans was not found to be exactly proportional to the number of revolutions, or rather squared revolutions, although the figures approximated to each other much nearer on the same day than on different days. It was therefore decided to make two* preliminary experiments with the agitators on the same day as each calorimeter experiment, and to subtract the agitator calories from the total calories obtained. As the number of revolutions was not exactly the same in the test experiments and in calorimeter experiments, the calories for correction were calculated in proportion to the revolutions in the test experiment, of course previously squaring the revolutions.

The following table shows in calories the heat produced by the ventilators during forty minutes from a few experiments, the number of revolutions is about 230,000, and the calories are calculated for 200,000 :—

On 200,000 Revolutions.

Date.	Calories.	Means.
4th January, 1897........	6866 5974	6420
8th „	6132 5559	5845
9th „	5511 5735	5623
10th „	5323 5780	5551
11th „	4901 4658	4779
14th „	6120 5956 6463	6434

* When time was pressing only one was made.

From these experiments the mean error is 218 calories, or on, say, 70,000 (emitted in forty minutes) = 0·3 per cent.

I now felt able to rely on the work undertaken with the calorimeter; still the instrument had to be tested, and with this object it was applied to the determination of the heat lost by a jar holding 6 or 7 litres of hot water and comparing the heat recovered with the heat lost by the water; the calorimeter was also used towards the estimation of the heat produced by the combustion of a known volume of pure hydrogen gas, comparing the heat recovered with that known to be produced by the combination of that volume of gas with oxygen, and this work I undertook in conjunction with R. B. Floris, F.C.S.

The first set of experiments with hot water proved very troublesome. It was found necessary to mix the layers of water in the jar before and after the experiment, and to read correctly and quickly a thermometer registering up to 0·02 of a degree centigrade; moreover the loss of heat could not be determined while the jar was being carried to and shut up in the calorimeter; and a similar difficulty was experienced on removing the jar from the calorimeter at the end of an experiment. Notwithstanding these many causes of error, as will be seen in the following table, the mean of the results approximated very closely to the calories calculated from the loss of heat of the water.

If, for instance, the jar contained 6 litres of water or 6000 grams, and lost 10° of temperature in the calorimeter, say, from 75° to 65° C., then 60,000 calories, with slight corrections for the specific heat of water at that temperature, and the thermal capacity of the jar, would have to be found in the calorimeter.

These experiments are tabulated as follows:—

	Calories found.	Calories lost by radiation.	Difference.
	57,451	58,468	−1·74 per cent.
	49,345	53,659	−8·04 ,,
	61,760	62,480	+1·15 ,,
	59,432	59,141	+0·49 ,,
	60,383	61,085	−1·15 ,,
	63,323	64,392	−1·66 ,,
	63,226	60,410	+4·66 ,,
	65,882	66,575	−1·04 ,,
	61,873	59,566	+3·87 ,,
	63,016	66,250	−4·88 ,,
	51,940	55,033	−5·62 ,,
Mean..	59,785	60,642	−1·41 ,,

Although there was in one case as much as 8·04 per cent. difference between the calories found and the calories lost from the jar, still the mean of the eleven experiments differs only by 1·41 per cent., which is a near result considering the difficulty of the experiment.

The determination of the heat produced by the combustion of hydrogen was certainly a more satisfactory method than the former for testing the calorimeter; hydrogen was prepared for the purpose in the usual way by the action of sulphuric acid on zinc, the gas being purified through solutions of potassium hydrate and cupric sulphate, and collected over water in a bell-jar carefully graduated. The receiver was supplied with a gauge, showing the pressure to which the gas was subjected, and a thermometer; from 20 to 29 litres of gas were used in each experiment.

After making the required preliminary essays with the agitators, the experiment was proceeded with as follows:—

First of all it was necessary to find out and to adjust carefully the speed of the gas delivery, and with that object a weight was placed on the bell-jar, while the rate of issue of the gas was regulated at will by means of a screw clamp on the track of the gas tube.* In that way the speed of the gas delivered was adjusted so as to produce on burning about the same heat as a person would emit in the calorimeter in a given time.

The delivery tube led from the bell-jar into the calorimeter through a fixed metal tube carried across the walls of the two chambers of the calorimeter, its end being connected with a suitable burner; when lighted, the gas burnt with but a very small flame.

Before commencing the experiment the tube was rinsed out with hydrogen and the thermometers were read, together with the pointer on the scale of the bell-jar. Then the gas was turned on and lighted, the vessel containing the ice hung in position, the stop-watch started, the calorimeter closed, and the agitators put in motion. Of course every care was taken to keep the temperature of the calorimeter constant, which was done without any difficulty, the temperature of the copper varying seldom by more than 0·1° or 0·2° C.

When forty minutes or an hour had elapsed (mostly forty minutes), the temperatures were read, the gas turned off, and the agitators stopped. Next the calorimeter was rapidly opened, and the flow of water from the ice to the flask arrested; the temperature of the ice water was then read off, these various operations being carried out as rapidly as possible. It was necessary to determine the heat absorbed by the burner, which was done by plunging the burner, immediately after turning off the gas, into 200 c.c. of water at a

* The gas was carried as much as possible through glass tubing, in order to avoid the loss by diffusion through india-rubber.

known temperature and determining the rise of temperature of the water; the burner was found to absorb 300 calories during the experiment. The pointer showed on the scale of the bell-jar the volume of hydrogen burnt, and the gauge the pressure the gas was under in millimetres of water, while a thermometer gave the temperature of the gas in the bell-jar, and a barometer the atmospheric pressure; the hydrogen gas was of course saturated with water vapour. Hence we were in possession of every data for the reduction of the gas to the dry state, to 0° C., and 760 mm. pressure.

In the early experiments it did not occur to us to analyse the hydrogen gas in order to ascertain its degree of purity, but we did so subsequently, using for that purpose the eudiometer constructed by one of us (W. M.), which for several years has been exclusively adopted in this laboratory for the determination of oxygen in expired air; the analysis of the gas introduced but a very slight correction. The following table gives the results of the experiments we made on the heat emitted by the combustion of a given weight of hydrogen gas. It might be added that the machine known as "Brunsviga" was used for the calculations, which saved much time and trouble; by this means the whole of the calculations could be completed in about fifteen minutes.

Favre and Silbermann find 1 gram of H to give in burning 34,462 calories.

	Found.	Difference.
1	33,334	3·26 low per cent.
2*........	33,159	3·78 ,, ,,
3*........	35,291	2·41 high ,,
4	35,186	2·10 ,, ,,
5*........	34,212	0·73 low ,,
6*........	35,610	3·33 high ,,
7	33,923	1·56 low ,,
8	34,079	1·11 ,, ,,
9	34,440	0·06 ,, ,,
10	35,048	1·70 high
Mean....	34,428	0·10 low ,,

Favre and Silbermann........	34,462
Marcet and Floris............	34,428
	34 = 0·1 per cent.

The present result is certainly convincing, and these figures are plain statements of all the experiments we made. The greatest

* In these experiments the hydrogen gas was not analysed; it was analysed in all the others and the correction therefrom introduced.

difference is only one of 3·78 per cent., and the mean difference did not exceed 34 calories on 34,462, amounting to 0·1 per cent. only. It may therefore be concluded that the present calorimeter has proved itself very accurate for the determination of the heat produced by the combustion of a given volume of hydrogen gas; and, consequently it can be accepted as equally reliable for the correct estimation of the heat radiated from the human body or from that of a fairly large animal.

"An Experimental Enquiry into the Heat given out by the Human Body." By W. MARCET, M.D., F.R.S., and R. B. FLORIS, F.C.S. Received March 10,—Read April 28, 1898.

(From the Physiological Laboratory of University College, London.)

Dr. Marcet's calorimeter having been fully described in the previous paper, the present conjoint authors now submitted themselves to experiment, one of them remaining shut up in the chamber, usually for the space of an hour, while the other was engaged outside to regulate the temperature of the chamber and note the readings of the thermometers.

When breathing was carried on inside the calorimeter, it might be thought that the air of the chamber became too full of CO_2 or too deficient in oxygen for the purposes of respiration. Such, however, was not the case, and no discomfort whatever was experienced in the course of an hour's incarceration. It is easy to calculate from a consumption of, say, 26·488 grams of O per hour that supposing the calorimeter to be absolutely air-tight, a condition which was not actually realised, there would be a fall of oxygen, after one hour spent in the calorimeter, equal to a reduction of pressure from 760 mm. to 668 mm., and this would correspond to an elevation of about 7000 feet (2135 metres) above the sea level. Such an altitude would certainly not be trying to the respiration.

The experiment was carried out as follows in every instance:—

Previous to entering the chamber the subject of the experiment sat down in the laboratory to rest, in many instances taking his temperature, sublingual, with a clinical thermometer.

In the meantime a weight of ice varying between 10 lbs. and 15 lbs. (4·5 to 6·8 kilograms), according to circumstances, was cut into blocks about 2 or 3 inches diameter, and placed in the ice holder, where the blocks were disposed as much as possible in a position to allow the air from the agitator to circulate freely between them. A temporary receiver for the water from the melting ice was hung to a